PORTLAND HARBOR RI/FS

APPENDIX P

COMPREHENSIVE BENTHIC APPROACH

DRAFT FEASIBILITY STUDY

DRAFT

Privileged and Confidential:
Work Product Prepared in Anticipation of Litigation

~~February 2012~~
March 2015

Prepared for
The Lower Willamette Group

Prepared by
Windward Environmental, LLC

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LIST OF ACRONYMS

AOPC	Area of Potential Concern
BERA	Baseline Ecological Risk Assessment
COPC	contaminants of potential concern
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
EPA	U.S. Environmental Protection Agency
FPM	Floating Percentile Model
FS	feasibility study
HCH	Hexachlorocyclohexane
HPAH	High-molecular-weight Polycyclic Aromatic Hydrocarbon
HQ	Hazard Quotient
LOE	Line of Evidence
LPAH	Low-molecular-weight Polycyclic Aromatic Hydrocarbon
LRM	Logistic Regression Model
LWG	Lower Willamette Group
MQ	Mean Quotient
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PEC	probable effects concentration
pMax	Maximum probability of toxicity
SMA	sediment management area
SPI	Sediment Profile Imaging
SQG	Sediment Quality Guideline
SQV	sediment quality value
SVOC	Semivolatile Organic Compound
TBT	Tributyltin
total DDx	Sum of all six DDT isomers (2,4′-DDD, 4,4′-DDD, 2,4′-DDE, 4,4′ DDE, 2,4~~′-~~′-DDT, and 4,4′-DDT)
TRZ	Toxicity Reference Value
TZW	Transition Zone Water

EXECUTIVE SUMMARY

This appendix ~~presents the identification of~~identifies the areas posing potentially unacceptable risk to the benthic community for use in the draft Feasibility Study (FS) based on the comprehensive benthic risk approach developed by the Lower Willamette Group (LWG) following direction given by the U.S. Environmental Protection Agency (EPA). ~~This~~The appendix details the methods for identifying Comprehensive Benthic Risk Areas and the rationale for the delineation of each of these areas. Maps of the Comprehensive Benthic Risk Areas are included ~~in~~as Attachment 1 ~~of~~to this ~~Appendix~~appendix. The Comprehensive Benthic Risk Areas are part of Sediment Management Area (SMA) and comprehensive remedial alternative development, as explained in Section 5.3 of the draft FS.

1.0 COMPREHENSIVE BENTHIC APPROACH

The identification of the areas posing potentially unacceptable risk to the benthic community for use in the draft Feasibility Study (FS) was based on the comprehensive benthic approach developed by the Lower Willamette Group (LWG) following direction given by the U.S. Environmental Protection Agency (EPA) in ~~its letter of~~ letters dated April 21, 2010 ~~(EPA 2010), see draft FS Appendix O. In that letter~~(EPA 2010), and April 4, 2014 (EPA 2014) (see draft FS, Appendix O). In those letters, EPA specified how areas were to be identified and how alternatives were to be evaluated relative to the protection of the benthic community:

- All benthic sediment quality guidelines (SQGs) in the March 24, 2010, list (EPA 2010) will be included in the analysis. If specific SQGs are found to be inconsistent with other lines of evidence (LOEs) listed below, EPA will review the analysis and determine whether these should be included in the draft FS.[1]
- Sediment toxicity bioassays will form the primary LOE for this analysis. ~~The sediment toxicity LOE will include level 2 (moderate) and level 3 (severe) effects for all four endpoints (*chironomus* [sic] biomass and mortality and *hyalella* [sic] biomass and mortality).~~The sediment toxicity LOE will include Level 2 (moderate) effects for three endpoints (i.e., *chironomus* [sic] biomass and mortality and *hyalella* [sic] survival) and Level 3 (severe) effects for all four endpoints (i.e., *chironomus* [sic] biomass and mortality and *hyalella* [sic] biomass and mortality) (Shephard 2014).
- The analysis will consider the number and degree of ~~exceedance of SQGs~~SQG exceedances.
- The analysis will consider other LOEs such as transition zone water (TZW) compared ~~to~~with ambient water quality criteria for the protection of aquatic life and benthic tissue toxicity reference values (TRVs~~.~~).
- The analysis will consider the presence/absence of nearby sources and examine benthic community structure (e.g., via sediment profile imaging and related information).
- The analysis will consider data quality and data density issues for the SQGs.

[1] ~~The SQVs have subsequently been revised based on additional modeling and negotiations between the LWG and EPA, as documented in Item 11 of Attachment B to a January 12, 2011, LWG letter to EPA (LWG 2011a), the attachment to a February 25, 2011, Remedial Investigation (RI)/FS schedule letter from EPA to the LWG (Humphrey 2011), and the LWG's March 9, 2011, draft response (LWG 2011b) to EPA's February 25, 2011, letter.~~ The SQVs have subsequently been revised based on additional modeling and negotiations between the LWG and EPA, as documented in Item 11 of Attachment B to a January 12, 2011, LWG letter to EPA (LWG 2011a), the attachment to a February 25, 2011, Remedial Investigation (RI)/FS schedule letter from EPA to the LWG (Humphrey 2011), and the LWG's March 9, 2011, draft response (LWG 2011b) to EPA's February 25, 2011, letter.

In both the ~~draft final~~ Baseline Ecological Risk Assessment (BERA) (Windward 2013) and the draft FS, the primary LOE for identifying benthic community risks was sediment toxicity, represented by survival and growth of the amphipod *Hyalella azteca* and chironomid midge *Chironomus dilutus* in a laboratory setting. When measured toxicity results were not available, toxicity was predicted based on Site-specific sediment quality values (SQVs) derived from multi-variable statistical models (i.e., the Floating Percentile Model [FPM] ~~[Avocet 2003] and the~~ (Avocet 2003)], Logistic Regression Model [LRM] ~~[Field et al. 1999]).[2] Both~~(Field et al. 1999)], and probable effects concentration [PECs] (MacDonald et al. 2000)).[3] These models estimate the probability of toxicity above a suite of threshold chemical concentrations (i.e., SQVs) derived for the mixture of chemicals found at the Site~~.~~, or, in the case of PECs, values calculated by third parties from non-Site-specific data and added to the comprehensive benthic approach at EPA's behest.

Because the predictive models are statistical, results are correlative and do not conclusively identify contaminants causing toxicity.[4] ~~Both~~All modeling approaches were used to identify contaminants whose sediment concentrations, when considered in aggregate, appear to help explain the observed toxicity and~~,~~ to identify threshold concentrations for each contaminant above which toxicity was likely to occur (Table 1).[5]

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Table 1. Contaminants Potentially Contributing to Benthic Risk Based on Predicted Sediment Toxicity LOE

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Contaminant	
Metals	
Cadmium	Lead
Chromium[a]	Mercury[a]
Copper	Silver
PAHs	
2-Methylnaphthalene	Dibenzo(a,h)anthracene
Acenaphthene	Fluoranthene
Acenaphthylene	Fluorene
Anthracene	Indeno(1,2,3-cd)pyrene

~~[2] See Section 6.2 and Attachment 6 (Part F) of the draft final BERA for further information.~~
[3] See Section 6.2 and Attachment 6 (Part F) of the BERA (Windward 2013) for further information.
[4] Risk conclusions based on the secondary benthic LOEs—tissue residue, surface water, and TZW—identify contaminants posing potentially unacceptable risk (i.e., contaminants of potential concern [COPCs~~)~~]) and are noted in Sections 12.1 and 12.2 of the draft final BERA~~.~~ (Windward 2013).
[5] The contaminant list is a combination of SQVs derived using the FPM and the LRM. Each SQV has a different reporting basis depending on the normalization selected for the model. All FPM SQVs were dry~~-~~weight normalized. LRM SQVs used a number of different normalizations, including dry weight, organic carbon, percent fines, and combinations of normalizations.

Table 1. Contaminants Potentially Contributing to Benthic Risk Based on Predicted Sediment Toxicity LOE

Contaminant	
Benzo(a)anthracene	Phenanthrene
Benzo(b)fluoranthene	Pyrene
Benzo(b+k)fluoranthene	Total HPAHs
Benzo(g,h,i)perylene	Total LPAHs[a]
Benzo(k)fluoranthene	Total PAHs
Chrysene	
Phthalates	
Dibutyl phthalate	
SVOCs	
Benzyl alcohol	Dibenzofuran[a]
1,2-Dichlorobenzene	Carbazole[a]
Phenols	
4-Methylphenol[b]	Phenol
PCBs	
Total PCBs[a]	
Pesticides	
2,4′-DDD	beta-HCH
4,4′-DDD	delta-HCH[a]
4,4′-DDE	Dieldrin
4,4′-DDT	Endrin
Sum DDD[a]	Endrin ketone
Sum DDE	cis-Chlordane
Sum DDT	Total endosulfan[b]
Total DDx	
Petroleum Hydrocarbons	
Diesel-range hydrocarbons	

Notes:

[a] FPM SQVs based on one or two endpoints are less than the apparent effect threshold and ~~may~~therefore might contribute to false predictions of toxicity.

[b] All SQVs derived from the FPM are less than the apparent effect threshold and therefore may contribute to false predictions of toxicity.

DDD – dichlorodiphenyldichloroethane
LOE – line of evidence

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DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
FPM – floating percentile model
HCH – hexachlorocyclohexane
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SQV – sediment quality value
SVOC – semivolatile organic compound
total DDx – sum of all six DDT isomers (2,4′-DDD, 4,4′-DDD, 2,4′-DDE, 4,4′-DDE, 2,4′-DDT, and 4,4′-DDT)

1.1 IDENTIFICATION OF COMPREHENSIVE BENTHIC RISK AREAS

Because the primary benthic LOE (bioassay results) does not identify the cause of the empirical toxicity, delineating areas posing potentially unacceptable ~~risks~~risk to the benthic community based on the magnitude of single chemical concentrations is highly uncertain. Rather, the draft FS focused on the empirical evidence of toxicity, along with predictions of toxicity (exceedances of a suite of SQVs derived from ~~two~~three models), to identify spatial aggregations representing areas that pose potentially unacceptable ~~risks~~risk to the benthic community (i.e., comprehensive benthic risk areas). A weight of evidence framework that combined the frequency and magnitude of empirical toxicity, frequency and magnitude of toxicity predictions, concordance between models and endpoints, results from other LOEs (i.e., benthic tissue burdens and TZW water quality exceedances), and spatial distribution of endpoints indicating potentially unacceptable risk composed the comprehensive benthic approach. Because surface water quality is not location specific, it was not used to delineate comprehensive benthic risk areas (although it was used to confirm the contribution of specific chemicals to areas posing potentially unacceptable ~~risks~~risk to the benthic community in specific reaches of the Site). Sediment profile imaging (SPI) data were not used in the development of comprehensive benthic risk areas because the information was qualitative and the SPI results did not identify any additional comprehensive benthic risk areas; rather, the SPI results generally indicated that benthic community structure could be explained by physical habitat characteristics and hydrological regime~~.~~ (Windward 2013).

Comprehensive benthic risk areas were identified based on the LWG's application of the comprehensive benthic approach. ~~Results were originally presented in~~ Maps ~~12-1a and 12-1b of the draft final BERA,~~are included herein as Attachment 1 to this appendix.

~~Empirical~~Locations where empirical bioassay results ~~indicating~~indicated significant toxicity formed the core of a comprehensive benthic risk area. Predictions of toxicity or bioaccumulation at surrounding chemistry-only ~~locations surrounding empirical, toxic locations~~stations were used as part of the weight of evidence that the area posed potentially unacceptable ~~risks~~risk to the benthic community. In areas where no empirical bioassay data were available, predicted toxicity was sufficient to identify comprehensive benthic risk areas. Significant bioaccumulation in either field-collected or laboratory-exposed organisms provided an independent LOE to either corroborate the identification of a comprehensive benthic risk area or provide ~~unique~~other evidence that a comprehensive benthic risk area was present.

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TZW locations with ~~chemistry~~chemical concentrations that, because of magnitude, ~~was~~were unlikely to be addressed by source control alone, also contributed to the identification of comprehensive benthic risk areas.

Sediment chemistry used to predict toxicity was represented as an aggregate value based on ~~an~~ average exceedance ~~factor~~factors (i.e., mean ~~quotient [MQ~~quotients [MQs]) across the entire FPM and PEC SQV ~~set~~sets. This MQ method of quantifying the concentrations of multiple chemicals that may be contributing to the potentially unacceptable risk to the benthic community has been used widely at other sites throughout the United States and was required by EPA in the problem formulation in the BERA~~.~~ (Windward 2013). Predictions of toxicity based on the LRM were represented as the maximum probability of toxicity (pMax) across all chemicals with some potential contribution to the toxicity observed ~~toxicity seen~~ in the empirical bioassays. Decision thresholds selected by EPA for use in the BERA (Windward 2013) were retained for the comprehensive benthic approach (i.e., an MQ greater than or equal to 0.7, for both LRM and PEC models and a pMax value greater than or equal to 0.59 for the LRM model).

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Details of the approach used to identify comprehensive benthic risk areas are as follows:

~~1. Areas of potential concern (AOPCs) based on multiple LOEs (i.e., benthic community, fish, wildlife, and human health endpoints) were developed by EPA prior to submittal of the draft final BERA.~~

1. Areas of potential concern (AOPCs) based on multiple LOEs (i.e., benthic community, fish, wildlife, and human health endpoints) were developed by EPA prior to submittal of the BERA (Windward 2013).
2. Locations within these broader AOPCs with empirical bioassay results indicating significant toxicity were identified.
    ~~a. Significant toxicity was considered to be one toxicity endpoint (*Chironomus* biomass or growth or *Hyalella* biomass or growth) exceeding a level 3 threshold, or two endpoints exceeding a level 2 threshold.~~
    a. Significant toxicity was considered to be one toxicity endpoint exceeding a Level 3 threshold, or two endpoints exceeding a Level 2 threshold (Shephard 2014).
        i. Level 3 threshold: Four empirical toxicity test endpoints (i.e., *Chironomus* biomass or growth or *Hyalella* biomass or growth).
        ii. Level 2 threshold: Three empirical toxicity test enpoints (i.e., *Chironomus* biomass or growth or *Hyalella* survival)
3. Locations without bioassay data~~,~~ but where significant sediment toxicity was predicted based on sediment chemistry ~~exceeding an MQ of 0.7 or a pMax of 0.59~~exceedances were identified.
    a. Sampling locations where ~~both~~at least two of the ~~MQ and pMax~~three models' thresholds were exceeded were considered toxic.

b. Sampling locations where ~~neither the MQ nor pMax~~no threshold or only one threshold was exceeded were considered non-toxic.

~~. Sampling locations where the models disagreed (i.e., either the MQ or the pMax threshold was exceeded, but not both) were considered uncertain by the predictive toxicity LOE.~~

~~5.~~4. Locations where empirical tissue residues or~~, in the absence of~~ predicted tissue residues (when empirical tissue residue data~~, predicted tissue residues~~ were absent) exceeded their ~~toxicity reference values (~~TRVs~~)~~ were identified.

a. The evidence of risk provided by measured or predicted exceedance of metals TRVs was considered weak because of species-specific differences in metals sequestration or other bioregulation; such evidence was not used to identify comprehensive benthic risk areas.

b. The evidence of risk provided by a predicted exceedance of the tributyltin (TBT) TRV was considered weak because of high uncertainty in the TBT bioaccumulation model and the selected TRV. Bioaccumulation (predicted or measured) of this chemical was not used to identify comprehensive benthic risk areas.

~~6. TZW exceedance areas with hazard quotients (HQs) greater than 100 were delineated (see Section 12.2 of the draft final BERA for derivation of this factor).~~

5. ~~All individual~~TZW exceedance areas with hazard quotients (HQs) greater than 10 and 1.0 were delineated separately (see Section 6.6.3.3 of the BERA (Windward 2013) for explanation of why 10 is a conservative threshold for the TZW HQ).

~~7.~~6. Individual sample results representing each benthic LOE were overlaid on a map.

a. Comprehensive benthic risk areas were identified where two or more adjacent sampling locations indicated potentially unacceptable risk to the benthic community based on either emipirical or predicted toxicity, empirical or predicted bioaccumulation, empirical TZW chemistry, or a combination of bioassay and chemistry LOEs.

i. Because emipirical toxicity ~~is~~was the primary LOE, toxicity predicted by chemistry exceedances (i.e., MQs or pMax) were overridden by no-hit bioassays where these lines co-occurred.

b. TZW exceedance areas (based on HQs greater than ~~100~~10) were identified as comprehensive benthic risk areas.

c. Boundaries of the comprehensive benthic risk areas split the distance between sampling locations exceeding criteria and the surrounding clean sampling locations, except where:

i. Other physical features ~~were present~~ (e.g., pier, channel edge, property boundary~~),~~) were present, in which case the boundaries were drawn at the physical features.

ii. The nearest sampling location exceeding criteria was at a distance greater than 200 feet[6] from a clean sampling location, in which case the boundary was drawn at a subjective distance less than halfway to the nearest clean sampling location.

1.2 RESULTS

The results of the application of the comprehensive benthic approach are presented in Attachments 1 and 2~~.~~ to this appendix. Table 2 summarizes the rationale for the delineation of a comprehensive benthic risk area.

Table 2. Rationale for Delineation of Each Comprehensive Benthic Risk Area

AOC	Is it a Comprehensive Benthic Risk Area?	Rationale
1A-1	Yes	Five locations with empirical and predicted ~~PCB~~ bioaccumulation above TRVs ~~cluster~~were clustered together along the shoreline.
1A-2	No	Only ~~one~~two bioassay and one chemistry location exceeded their respective thresholds. Two predicted ~~polychlorinated biphenyl (PCB)~~ bioaccumulation locations were not contiguous with the risk area.
2	No	~~Single, isolated~~Three bioassay ~~hit.~~ Level 2 or 3 hits. No other LOE indicating toxicity.
3-1	No	~~Six~~Seven locations with significant toxicity or actual or predicted bioaccumulation ~~are~~were spatially isolated.
3-2	Yes	Twelve locations with significant toxicity and bioaccumulation (either empirical or predicted) ~~form~~formed a cluster.
4	No	Single, isolated bioassay Level 3 hit with no other LOE indicating toxicity.
5-1	Yes	Three empirical toxicity locations ~~form~~formed a cluster.
5-2	No	~~No LOE~~Two bioassay locations indicating toxicity were spatially isolated.
6-1	Yes	~~Six~~Eight locations with predicted toxicity ~~form~~formed a cluster.
6-2	No	~~No LOE indicating toxicity.~~Two locations with empirical or predicted toxicity; locations were spatially isolated.
7	No	No LOE indicating toxicity.
8-1	No	Two locations with significant toxicity ~~are~~were spatially isolated.
9D-1	No	~~Eight~~Fourteen locations with significant empirical or predicted toxicity ~~are~~or predicted bioaccumulation were spatially separated by non-toxic locations.

[6] This distance is based on best professional judgment. Conditions within Portland Harbor tend to be localized with few apparent gradients. In addition, sampling density varied with mid-channel samples being the least dense, necessitating selection of some distance to delineate a cluster of samples that had some likelihood of being associated with similar sources.

Table 2. Rationale for Delineation of Each Comprehensive Benthic Risk Area

AOC	Is it a Comprehensive Benthic Risk Area?	Rationale
9D-2	Yes	Three locations with empirical or predicted toxicity ~~form~~formed a cluster.
9D-3	Yes	Five locations with predicted toxicity ~~form~~formed a cluster.
9U-1a	Yes	Twenty-six locations with significant toxicity, bioaccumulation, and TZW HQs greater than 100 ~~form~~formed a cluster.
9U-1b	Yes	~~Forty~~Fifty-one locations with significant toxicity, bioaccumulation, and TZW HQs greater than ~~100 form~~10 formed a cluster.
9U-2	No	No LOE indicating toxicity.
10	No	~~No LOE~~Two stations indicating empirical toxicity; locations were spatially isolated.
11	No	Single isolated prediction of toxicity; no other LOE indicating toxicity.
12	No	Single isolated prediction of toxicity; no other LOE indicating toxicity.
13-1	No	~~Three~~Eight locations with significant empirical or predicted toxicity or empirical bioaccumulation ~~are~~were spatially separated by non-toxic locations.
13-2	Yes	~~Four~~Five locations with empirical or predicted toxicity or bioaccumulation ~~form~~formed a cluster.
13-3	Yes	Two locations with empirical or predicted toxicity ~~are~~were adjacent to a previously remediated area.
14-1	No	~~Locations~~Six locations with significant empirical or predicted toxicity or bioaccumulation ~~are~~were spatially separated by non-toxic locations.
14-2	Yes	Two locations with empirical or predicted toxicity ~~form~~formed a small cluster.
14-3	Yes	~~Thirty-five~~Fourth-three locations with significant toxicity, bioaccumulation, and TZW HQs greater than ~~100 form~~10 formed a cluster.
14-4	Yes	Two locations with empirical or predicted toxicity ~~form~~formed a small cluster.
15	No	No LOE indicating toxicity.
16	No	~~Three~~Four locations with empirical and predicted toxicity ~~are~~were spatially separated by intervening clean locations.
17D-1	No	~~Two~~Nine locations with either ~~empirical~~toxicity or predicted ~~toxicity are~~bioaccumulation were spatially isolated.
17S-1	No	Locations with significant toxicity or bioaccumulation ~~are~~were spatially separated.

Table 2. Rationale for Delineation of Each Comprehensive Benthic Risk Area

AOC	Is it a Comprehensive Benthic Risk Area?	Rationale
17S-2	Yes	~~Two~~Ten locations with either empirical or predicted toxicity ~~form~~or bioaccumulation formed a cluster.
17S-3	Yes	~~Two~~Three locations with predicted toxicity or bioaccumulation ~~form~~formed a cluster.
18	No	~~Two~~Six locations with predicted and empirical toxicity ~~are~~were spatially isolated.
19-1	No	~~Two~~Four locations with significant predicted and empirical toxicity ~~are~~were spatially isolated.
19-2	Yes	~~Empirical~~Eleven locations with empirical and predicted toxicity and bioaccumulation locations ~~form~~formed a cluster.
19-3	Yes	~~Empirical~~Five locations with empirical and predicted toxicity and predicted bioaccumulation locations ~~form~~formed a cluster.
20	No	~~Single,~~Two locations, one isolated bioaccumulation location~~; no~~ and the other ~~LOE indicating~~one empirical toxicity location were spatially isolated.
21	No	No LOE indicating toxicity.
22	No	No LOE indicating toxicity.
23	No	~~No LOE indicating~~One location with empirical toxicity was spatially isolated.
24	No	No LOE indicating toxicity.
25-1	No	Two locations indicating significant bioaccumulation ~~are~~were spatially isolated.
25-2	Yes	~~Six PCB~~Eight locations with predicted toxicity and six bioaccumulation locations ~~form~~formed a cluster~~; no other LOE indicating toxicity~~.
26	No	No LOE indicating toxicity.

~~**Notes:**~~
AOC – area of concern
HQ – hazard quotient
LOE – line of evidence
~~PCB – polychlorinated biphenyl~~
TRV – toxicity reference value
TZW – transition zone water

Eighteen comprehensive benthic risk areas were identified based on sediment toxicity, bioaccumulation, and TZW LOEs. ~~Three~~One comprehensive benthic risk area (1A-1) was identified based solely on the bioaccumulation LOE. Six comprehensive benthic risk areas (9D-2, 9U-1a,13-3, 14-2, 14-4, 17s-2) were identified based ~~solely on the bioaccumulation LOE (1A-1, 17S-3,~~ on toxicity, both predicted and ~~25-2).~~empirical. One comprehensive benthic risk area (5-1) was identified based solely on empirical bioassay results, while two others (6-1 and 9D-3) were identified based solely on predicted

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toxicity. Three comprehensive benthic risk areas (9U-1a, 9U-1b, and 14-3) had TZW TRV HQs exceeding ~~100~~10; however, other LOEs also indicated toxicity in these areas.

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Attachment 1
Mapped Results of the Comprehensive Benthic Approach

Attachment 2
Data Results of the Comprehensive Benthic Approach